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Boron Toxicity in Young 'Sharwil' Avocado Trees

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Abstract. Boron (B) fertilization is recommended for production of avocado [*Persea americana* Mill. (*P. gratissima* C.F. Gaertn.) 'Sharwil'] trees grown in the Tropofolist soils of Kona, Hawaii. To determine the effect of excess B application, seven B treatments (0, 3.7, 11, 22, 44, 89, and 178 mg B kg^{-1} soil fines) were applied to one-year-old grafted 'Sharwil' avocado trees grown for 13 weeks in a Tropofolist soil in the greenhouse. Boron toxicity symptoms on young 'Sharwil' avocado trees were characterized by leaf tip and marginal necrosis, "crinkling" of the leaves, premature leaf abscission, depression of vegetative flushing, and stunted root growth. Increasing B application rates, particularly of or greater than 44 mg kg^{-1} soil fines, significantly depressed new leaf area, length of fine roots, and dry weights of new leaves, new stems, and tap roots. Average B concentrations in the leachate that were associated with a 10% reduction in dry weight and area of new leaves were 1.8($\pm$0.4) [4] and 2.4($\pm$0.5) mg L^{-1}, respectively. In these Tropofolist soils, leachate B concentrations, as an estimate of soil solution B levels, should be examined further as a possible predictor of B toxicity of avocados. Critical foliar B concentrations in 'Sharwil' avocados based on dry weight and area of new leaves ranged from 37($\pm$3) to 65($\pm$4) and from 31($\pm$10) to 78($\pm$13) mg kg^{-1} (dry weight), respectively. The recommended range of foliar B concentrations in 'Sharwil' avocados is 40 to 70 mg kg^{-1}; however, limitations are discussed.

The principal avocado cultivar grown in Hawaii is 'Sharwil' (Bittenbender et al., 1989), a cross between Mexican and Guatemalan races. Avocado production in the state is centered in the district of Kona on the island of Hawaii. Typical soils in this area are thin, organic soils (Tropofolists) that are underlain by lava (USDA-SCS, 1973).

During the 1989-90 harvest season in Hawaii, lopsided, misshapen fruits with deep creases near the stem end were observed (Bittenbender, 1990). These fruit deformities appeared to be similar to those reported in Australia by Piccone and Whiley (1987) and Broadley et al. (1991), which were caused by boron (B) deficiency. The cultivar Sharwil, in particular, was reported to be very susceptible to B deficiency (Piccone and Whiley, 1987). To determine the optimum B application rates for 'Sharwil' avocados grown in Kona, Hawaii, an on-farm trial was initiated (Miyasaka et al., 1992). However, due to the on-farm nature of this trial, B levels that could result in phytotoxicity were not planned.

A narrow range between boron deficiency and toxicity has been reported for many plants (Marschner, 1986). Boron toxicity could become a problem in avocado production due to excess B fertilization. Although experiments have been carried out in the past on B toxicity of avocado trees (Embleton and Jones, 1966), no information on B toxicity of the cultivar Sharwil was found. Variability in B accumulation and tolerance of B toxicity within the avocado germplasm is possible, because such genetic differences have been found in grapefruit (*Citrus paradisi* Macfady) rootstocks (Peynado and Sluis, 1979), olive (*Olea europaea*) cultivars (Benlloch et al., 1991), and wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) genotypes (Nable and Paull, 1991; Paull et al., 1988).

To determine the effect of increasing B application rates on 'Sharwil' avocados, a greenhouse trial was conducted with one-year-old, grafted

'Sharwil' trees. The objectives of this experiment were: a) to determine the effect of excess B fertilization on the vegetative growth of young 'Sharwil' avocado trees; b) to describe symptoms of B toxicity in 'Sharwil' avocados; and c) to determine foliar, soil, and leachate B levels that are associated with B phytotoxicity.

Materials and Methods

Avocado seeds from 'MAL-2-1' were germinated in February, 1991 in perlite under 50% shade and intermittent mist. They were transplanted to black 20 x 40 cm polyethylene pots containing 13.1 kg (oven dry weight) of rocks and soil fines from the Kaimu series (isohyperthermic, euic, Typic Tropofolist). Components of this medium were (on a dry weight basis): rocks larger than 25 mm in diameter, 20%; rocks between 25 and 6 mm, 38%; rocks between 2 and 6 mm in diameter, 24%; and soil fines less than 2 mm in diameter, 17%. The two larger rock fractions were mixed and placed at the bottom of the pot. The smallest rock fraction and the soil fines were mixed and placed over the larger rock fractions. The proportions of rocks and soil fines in this medium, and their distribution in the pot were based on measurements and observations from a Kaimu series soil profile which was located in a 'Sharwil' orchard. The soil and rock fractions were obtained from Waiea, Hawaii (19^{o} 22' N, 155^{o} 52' E).

In the unamended soil fines, total N was determined by a micro-Kjehldal method (Isaac and Johnson, 1976), organic carbon was measured by the method of Heans (1984), available P was analyzed by the modified Truog method (Ayers and Hagihara, 1952), and exchangeable cations were determined by the ammonium acetate (pH 7) method (Thomas, 1982). Hot water extractable B levels in the unamended soil fines were measured using the method of Mahler et al. (1984) and Wolf (1974).

Two and 11.5 months after seed germination, 50 g of Osmocote 13.5-13.5-13.5 (Sierra Chemical Co., Milpitas, CA) [5] were broadcast over the soil surface of each pot. Six months after seed germination, 'Sharwil' scionwood was grafted onto the 'MAL-2-1' seedling rootstock.

Six months after grafting, trees were randomized and blocks established on the basis of initial plant size and position on the greenhouse bench. Six B treatments (Table 1) were applied by pipetting 50 mL of appropriate concentrations of H_3BO_3 onto the soil surface. These treatments were used to simulate a one-time excess application of B fertilizer on avocado trees. There were a total of 30 pots, with four replicates of treatments 0 to 4 and five replicates of treatments 5 and 6 (Table 1).

Trees were irrigated with 500 mL day^{-1} (or 1.6 cm day^{-1}) of tap water that contained non-detectable concentrations of B (<0.01 mg B L^{-1}) as measured by the azomethine-H method (Wolf, 1974). After application of B treatments, total leachate volume for each pot was collected weekly in bottles to which several drops of toluene were added to prevent microbial growth. Leachate volume was measured, a subsample collected, and B analyzed (Wolf, 1974). Excess leachate was discarded.

Two weeks prior to the application of B treatments, approximately 12 leaves per tree were sampled from the youngest fully expanded flush of leaves. Then, nine weeks after the B application, approximately 7 leaves per tree were sampled from the youngest fully expanded flush of leaves. Leaves were rinsed three times in deionized water, blotted to remove excess moisture, dried at 75^{o}C to constant weight, and analyzed for total nitrogen by the micro-Kjehldal method (Isaac and Johnson, 1976; Nelson and Sommers, 1972) and for B by the azomethine-H method (Wolf, 1974). Concentrations of other elements (P, K, Ca, Mg, Mn, Fe, Cu, Zn, and Al) were determined using inductively-coupled plasma emission spectroscopy following wet-ashing (Isaac and Jones, 1972). Analyses were conducted by the Agricultural Diagnostic Service Center at the University of Hawaii - Manoa.

Mites (*Oligonychus biharensis*) were a pest on the avocado trees grown in the greenhouse. Malathion (Malathion 25W, FMC Corporation, Philadelphia, PA) was sprayed according to the label for control of these mites immediately prior to B application and four weeks later. Then, dienochlor (Pentac Aquaflow Miticide, Sandoz Crop Protection, Des Plaines, IL) was sprayed according to the label, to control these mites eight weeks after B application.

The experiment was terminated 13 weeks after initiation of B treatments. Stem diameters were measured above the graft union. Tree heights were measured at the start of B treatments and at the termination of the experiment, and the increase in height calculated. Leaves and stems were separated into new leaves and stems (those that developed after the initiation of B treatments) and old leaves and stems (those that developed before application of B treatments). Roots were washed free of media and separated into fine roots and the tap root. Leaf areas and fine root lengths were measured using a digital image analysis system (Decagon Devices, Pullman, WA). Fresh weights of these plant parts were measured, then dry weights were determined after drying at 75°C. A subsample of soil was collected from each pot after harvest, air-dried, sieved (<2 mm) and analyzed for B by the hot water extraction procedure (Mahler et al., 1984; Wolf, 1974).

Treatment effects were evaluated by analysis of variance (ANOVA) (SAS, 1982). Linear B (B), replicate, and quadratic B (B^2) effects were calculated. A probability level of 0.05 or less was considered to be statistically significant. Dry weight and area of new leaves were regressed against leachate and foliar B concentrations, using linear and several non-linear regression models (SAS, 1982). For non-linear regression models, the coefficient of determination (r^2) was calculated to be 1 - (Residual sum of squares/Corrected total sum of squares). Criteria in determining the regression model with the best fit for each relationship were the most significant r^2 value and examination of plots of residual values against predicted values for "goodness of fit." Standard errors of the mean for critical leachate and foliar B concentrations associated with 90% of maximum leaf areas or leaf dry weights were calculated using the delta method (Bishop et al., 1975).

To determine B sorption of this soil, B as boric acid (H_3BO_3) was added to duplicate 100-g samples of soil that were air-dried and sieved (< 2 mm). Rates of B applied in mg B kg^{-1} soil fines were: 0.0, 0.5, 1.0, 1.5, 2.0, 5.0, 10, 20, 50, 100, and 200. The soil fines were brought up to 15% water content and incubated in plastic bags for 18 days and analyzed for hot water extractable B (Mahler et al., 1984; Wolf, 1974).

Results and Discussion

Initial Soil Analyses. Analyses of the unamended soil fines were (on oven-dried soil basis): pH, 5.8; total N, 11.4 g kg^{-1}; organic carbon, 125 g kg^{-1}; dilute sulfuric acid-extractable P (Truog-P), 150 mg kg^{-1}. Exchangeable cations were, in mg kg^{-1} soil fines: K, 310; Ca, 3700; and Mg, 450. Hot water extractable B concentration in the unamended soil fines was 0.95 mg kg^{-1}. This level of extractable soil B should be adequate based on the range of water-soluble B from 0.59 to 2.58 mg kg^{-1} (on air-dried soil basis) found in California soils from healthy avocado orchards (Haas, 1943). However, it must be remembered that soil fines in this study comprised only 17% (dry weight basis) of this medium.

Extractable Soil B Concentrations. There was a linear increase in hot water extractable B concentration as the rate of added B increased (Fig. 1). In general, when soil extractable B concentration exceeds 5 mg B kg^{-1}, B toxicity symptoms in plants are likely to occur (Reisenauer et al., 1973). In this study, applied B greater than 8 mg kg^{-1} soil fines should have resulted in potentially toxic extractable soil B levels (Fig. 1).

Leachate B Concentrations. Leachate B concentrations were used to estimate concentrations of B in soil solution. Boron concentrations in the leachate averaged over the entire experimental period were approximately one-tenth that of added B and increased linearly with amounts of B added (Fig. 2).

Leachate Volume. Total volume of leachate increased with increasing B application rates (Table 2), and this effect was particularly evident at B rates of or greater than 44 mg B kg^{-1} fines. This increased leachate volume was observed at the end of the first month after B application, and was the first observable effect of excess B.

Boron Toxicity Symptoms. Foliar B toxicity symptoms of 'Sharwil' avocados were characterized by leaf tip and marginal necrosis, as well as interveinal chlorosis and necrotic spots similar to those symptoms observed on 'Fuerte' avocado seedlings (Haas, 1929). In addition, "crinkling" of leaves, premature leaf abscission, depression of vegetative flushing, and stunted fine root growth were observed. Although B toxicity effects on avocado roots have not been reported previously, stunting of root growth apparently is a characteristic symptom of B toxicity, because similar results were found for squash (*Cucurbita pepo* L.) roots (Lovatt and Bates, 1984). Foliar B toxicity symptoms were observed two months after B application; however, the first observable effect of excess B was increased leachate volume. Perhaps, the primary effect of B phytotoxicity on 'Sharwil' avocados involved root injury that was not readily observable.

These B toxicity symptoms were observed on 'Sharwil' seedlings treated with B rates of or greater than 44 mg B kg^{-1} soil fines. Such B application rates should result in initial soil extractable B levels of or greater than 18 mg B kg^{-1} soil fines (Fig. 1). This soil extractable B concentration greatly exceeds that of 5 mg B kg^{-1} soil reported by Reisenauer et al. (1973) to be toxic to a number of species. There are two possible explanations for this result. First, it should be noted that soil fines in this Tropofolist soil comprised only 17% of the total dry weight of the medium. Thus, a soil extractable B concentration of 18 mg B kg^{-1} soil fines could be considered to be "diluted" by inert rocks, resulting in an actual soil extractable B concentration of 3 mg B kg^{-1} medium.

A second explanation of this apparently higher level of soil extractable B required to produce B phytotoxicity in 'Sharwil' avocados was due to the leaching effect of daily irrigation. Thirteen weeks after establishment of B treatments, leaching had accounted for the losses of 23%, 21%, 21%, 44%, 48%, and 56% of the B applied to the following treatments: 3.7, 11, 22, 44, 89, and 178 mg B kg^{-1} soil fines, respectively. At harvest, extractable soil B was less than the reported general toxic concentration of 5 mg B kg^{-1} (Reisenauer et al., 1973), even at the highest application rate (Table 2). These results suggest that in this Tropofolist soil, frequent rainfall or irrigation will leach B readily out of the root zone. The implication for management of avocado orchards in a Tropofolist soil is that trees can recover from B phytotoxicity if rainfall is frequent or if excess irrigation is supplied.

Dry Weights and Areas of New Leaves. Dry weights of new leaves increased with the first increment of applied B and then decreased significantly with increasing B application rates (Table 3). Similarly, new leaf areas increased and then decreased significantly with increasing B rates (Table 3).

Boron concentrations in the leachate were used to estimate soil solution B concentrations that were phytotoxic to avocados. Leachate B concentrations were averaged over the entire experimental period, because of the change in extractable B levels during the study (Table 2).

Growth of new leaves were regressed against average leachate B concentrations using non-linear regression models (Fig. 3). Maximum dry weight of new leaves occurred at an average leachate concentration of 1.0 mg B L^{-1}, while 90% of maximum dry weight of new leaves were associated with average leachate B concentrations of 0.6($\pm$0.2) and 1.8 ($\pm$0.4) mg L^{-1} (Fig. 3A). Maximum leaf area was found at an average leachate concentration of 1.3 mg B L^{-1}, while 90% of maximum leaf area were associated with average B leachate concentrations of 0.7($\pm$0.2) and 2.4 mg ($\pm$0.5) L^{-1} (Fig. 3B).

It is evident that this Tropofolist soil is low in available B, because new leaf growth of 'Sharwil' avocado increased with the initial increment of B fertilizer (Table 3; Fig. 3). However, it is also clear that excess B application severely depressed new leaf growth (Table 3; Fig. 3).

Avocado has been reported to be sensitive to irrigation waters that exceed 1 mg B L^{-1} (Gupta et al., 1985). The results of this study are in agreement with this earlier observation, because a 10% reduction in dry weight and area of new leaves occurred at average leachate concentrations of 1.8($\pm$0.4) and 2.4 mg($\pm$0.5) B L^{-1}, respectively (Fig. 3).

In an earlier study, Haas (1929) found toxicity symptoms in 'Fuerte' avocado seedlings grown in sand cultures at 1 to 2 mg B L^{-1}. In this experiment, avocado seedlings grown in a Tropofolist soil did not exhibit toxicity symptoms at an average leachate concentration of 2 mg B L^{-1}, although a 10% reduction in maximum dry weight and area of new leaves is predicted to occur at this B concentration (Fig. 3). Instead, toxicity symptoms were found in

'Sharwil' avocado seedlings at leachate concentrations of or greater than 4.3 mg B L^{-1}.

There are three possible explanations for the apparently higher tolerance of 'Sharwil' avocados to solution B concentrations in this study compared to those found by Haas (1929). First, the trees were exposed to an initial high dose of B, which then declined over time as B was leached steadily from the soil profile due to irrigation. Perhaps, avocados can tolerate higher concentrations of B for a relatively short period of time compared to continuous exposure to a lower B concentration over a longer period of time.

Second, 'Sharwil' may be more tolerant of high B levels than other avocado cultivars. Certainly, it has been reported to be more susceptible to B deficiency than other cultivars (Piccone and Whiley, 1987). In cultivars of barley, wheat (Nable and Paull, 1991), and olive (Benlloch et al., 1991), greater tolerance to B and lesser accumulation of B in leaves were associated with greater susceptibility to B deficiency. Conversely, perhaps a greater susceptibility to B deficiency may be associated with a greater tolerance to excess B.

Third, a portion of the leachate B could have been complexed to non-phytotoxic, organic soil compounds. Complex formation between B and dihydroxy or hydroxy carboxylic functional groups of organic matter has been suggested to be of importance in reactions between B and organic matter in soils (Fleming, 1980). The high level of organic matter in this Tropofolist soil provides the possibility for formation of non-phytotoxic, B-organic matter complexes.

Dry Weight of New Stems. Increasing B applied significantly depressed the dry weight of new stems of avocados, particularly at rates of or greater than 44 mg kg^{-1} fines (Table 3). This decrease in dry weight of new stems at high B could be explained partly by decreased photosynthate production as a result of reduced photosynthetic leaf area that occurred at excess B levels (Table 3; Fig. 3).

Dry Weight of Tap Roots. Dry weight of avocado tap roots increased with initial increments of applied B and then decreased significantly with increasing B application, particularly at rates equal to or greater than 44 mg kg^{-1} fines (Table 4). This decrease in tap root growth was similar to the decrease in total root dry weight found for peanut (*Arachis hypogaea* L.) plants grown in sand culture at toxic levels of B (Gopal, 1973).

Dry Weights of Old Leaves, Stems, and Fine Roots. There was no significant effect of B treatments on dry weights of old leaves, old stems, or fine roots (data not shown). The average dry weight of old leaves was 4.97($\pm$1.26) g, that of old stems was 50.4($\pm$ 3.7) g, and that of fine roots was 12.4($\pm$ 1.2) g. In avocados, dry weights of old leaves, old stems, and fine roots are growth parameters that do not appear to be particularly sensitive to B toxicity.

Root lengths. Length of fine roots increased with initial increments of added B, and then significantly decreased with increasing B application rates, particularly at levels equal to or greater than 44 mg B kg^{-1} fines (Table 4). Apparently, fine root length of 'Sharwil' avocados was reduced by excess B to a greater degree than fine root dry weight. These results are similar to those of Lovatt and Bates (1984) for squash seedlings in which one of the earliest effects of B toxicity was an inhibition of root elongation that occurred within 72 h after exposure to excess B.

Heights and Diameters. There was no significant effect of B treatments on diameters of young 'Sharwil' trees. The average diameter above the graft union was 0.78 $\pm$ 0.03 cm. Stem diameter is a growth parameter of avocados that does not appear to be very sensitive to B toxicity.

The mean tree height prior to the initiation of B treatments was 95.3($\pm$4.3) cm. The increase in seedling height over 13 weeks was significantly reduced by increasing amounts of B, particularly at the highest B level (Table 4).

Foliar B Concentrations. Foliar B concentrations did not differ significantly among 'Sharwil' avocado trees prior to the start of the B treatments. The mean foliar B concentration was 69($\pm$ 4.8) mg B kg^{-1}.

Nine weeks after the start of the B treatments when phytotoxicity symptoms were first observed, foliar B concentrations increased with increasing B applied up to 89 mg B kg^{-1} fines and then decreased thereafter (B effect: P = 0.0008; B^2 effect: P = 0.0001; Fig. 4). Similar results were found for total B concentrations in leaves (B effect: P = 0.0001; B^2 effect: P = 0.02; data not shown).

To estimate the critical range of B concentrations in 'Sharwil' avocado leaves, growth of new leaves over a 13 week period were regressed against foliar B concentrations sampled 9 weeks after the start of B treatments, using non-linear models (Fig. 5). The critical B concentration range for 90% of maximum dry weight of new leaves was 37($\pm$4) to 65($\pm$5) mg B kg^{-1} (Fig. 5A), while that for 90% of maximum area of new leaves was 31($\pm$13) to 78 ($\pm$10) mg B kg^{-1} (Fig. 5B). These critical B concentration ranges for 'Sharwil' avocado seedlings are slightly lower than the adequate range of B reported for 'Fuerte' avocados of 50 to 100 mg B kg^{-1} (Embleton and Jones, 1966); however, the authors also stated that more confirming data was needed to support this recommended B range.

As discussed earlier, B toxicity symptoms were observed at levels equal to or greater than 44 mg B kg^{-1} fines. At these B levels, foliar B concentrations were greater than 190 mg kg^{-1} (Fig. 5). These results are within the range of

100 to 250 mg B kg^{-1} reported by Embleton and Jones (1966) to be in excess for avocado leaves.

Caution must be exercised when using these reported critical foliar B concentrations of 'Sharwil' avocados to predict B status of the tree. The first reason is that the 'Sharwil' trees used in this experiment to determine critical foliar B concentrations were grown in the greenhouse. In the field, B concentrations of avocado leaves sampled after a heavy rainfall could be erroneously low due to leaching of B from the leaves. In greenhouse-grown barley plants, simulated rain resulted in leaching of B from the leaves and a reduction of 14 to 29% compared to unleached plants (Nable et al., 1990).

The second reason is that leaf injury may not be a reliable indicator of yield reduction. In this experiment, only the vegetative parts of avocado trees were used to estimate critical B concentrations in the leaves and soil solution. In snap beans (*Phaseolus vulgaris* L.) and cowpeas [*Vigna unguilata* (L.) Walp.], yield reductions due to B toxicity occurred at lower soil solution B levels and lower leaf B concentrations than leaf injury (Francois, 1989). As with other crops, the best estimation of critical B concentrations in avocado leaves and soil solution should be based on the actual fruit yield. An on-farm fertilizer trial of 'Sharwil' avocados will determine critical B concentrations based on actual fruit yields (Miyasaka et al., 1992) and these results will be compared.

Conclusions

Soil extractable B does not appear to be a good predictor of B toxicity of avocados grown in Tropofolist soils, because the level that results in phytotoxicity could depend on the percentage of soil fines. This fraction of soil fines can vary considerably between sites and even within a farm.

Leachate B concentration, as an estimate of soil solution B concentration, appears to be a good predictor of B phytotoxicity. Leachate B levels that reduced growth of 'Sharwil' avocados by 10% are similar to those in irrigation water reported previously to cause B phytotoxicity (Gupta et al., 1985). Soil samples could be measured for leachate B concentrations as easily as for hot water extractable B concentrations. However, this method of measuring leachate B concentrations needs to be tested in the field for practicality.

Boron concentration in the youngest, fully expanded leaves appears to be the simplest and best predictor of B toxicity in 'Sharwil' avocados. A boron concentration range of 40 to 70 mg kg^{-1} (dry weight basis) is recommended for vegetative growth of 'Sharwil' avocados, with B toxicity occurring at foliar B concentrations greater than 100 mg kg^{-1}. However, there are two potential problems that could occur when using this range of foliar B concentrations to predict phytotoxicity: a) underestimation of foliar B levels in the field due to leaching of B from leaves by heavy rainfall ; and b) the optimum B concentration range reported here for 'Sharwil' is based on vegetative growth and may not be similar for fruit yield.

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TABLE 1. Amounts of B applied to pots containing grafted one-year-old 'Sharwil' avocado trees.

Treatment	B application rates		
	mg pot^{-1}	kg ha^{-1}	mg kg^{-1} soil fines
0	0	0.0	0.0
1	8	2.6	3.7
2	25	7.8	11
3	50	16	22
4	101	31	44
5	202	62	89
6	403	125	178

TABLE 2. Estimated initial extractable soil B, extractable soil B at harvest (13 weeks after exposure to B treatments), and total leachate volume (summed over 13 weeks).

Added B	Estimated initial extractable B [y]	Extractable B at harvest [z]	Total leachate volume
mg kg^{-1} soil fines	mg kg^{-1} soil fines	mg kg^{-1} soil fines	L
0.0	2.2	0.75 (0.05)	5.8 (1.1)
3.7	3.5	0.88 (0.09)	2.5 (0.4)
11	6.0	1.2 (0.14)	4.5 (1.3)
22	9.9	1.4 (0.18)	4.1 (1.3)
44	18	1.4 (0.16)	10.9 (2.8)
89	33	3.0 (0.47)	11.7 (2.5)
178	64	4.5 (0.57)	13.5 (2.1)

[y] Initial extractable B concentrations were estimated by the linear regression equation found in Figure 1.

[z] Means are followed by standard errors of the mean in parentheses.

TABLE 3. Dry weights of new leaves and new stems, and leaf areas of 'Sharwil' avocados as affected by increasing B application rates.

Added B	Dry weights: new leaves [z]	Dry weights: new stems	Leaf area
$mg\ kg^{-1}$ soil fines	g	g	m^2
0.0	18.6 (3.1)	15.3 (7.0)	0.30 (0.05)
3.7	28.0 (2.3)	10.7 (1.0)	0.43 (0.06)
11	21.2 (5.4)	8.8 (0.8)	0.41 (0.09)
22	26.1 (4.0)	12.6 (3.0)	0.45 (0.08)
44	7.7 (2.0)	8.6 (1.7)	0.25 (0.08)
89	8.6 (3.1)	6.9 (2.7)	0.19 (0.07)
178	8.8 (3.3)	4.0 (1.2)	0.16 (0.07)
<u>ANOVA: PR > F</u>			
B	0.002	0.02	0.003
Replicate	0.870	0.53	0.300
B^2	0.049	0.58	0.390

[z] Means are followed by standard errors of the mean in parentheses.

TABLE 4. Dry weight of tap roots, root lengths, and change in height of 'Sharwil' avocados as affected by increasing B application rates.

Added B	Dry weights tap roots [z]	Root length	Height change
mg kg^{-1} soil fines	g	g	m
0.0	25.8 (4.4)	27.0 (4.8)	0.40 (0.03)
3.7	30.8 (2.6)	28.6 (4.9)	0.30 (0.04)
11	29.1 (4.8)	27.0 (2.0)	0.28 (0.08)
22	31.6 (8.1)	31.1 (7.4)	0.26 (0.03)
44	18.4 (4.7)	20.1 (6.7)	0.26 (0.03)
89	17.8 (3.5)	20.4 (8.1)	0.36 (0.05)
178	20.9 (2.2)	15.0 (2.5)	-0.06 (0.32)
<u>ANOVA: PR > F</u>			
B	0.04	0.03	0.047
Replicate	0.12	0.42	0.610
B^2	0.09	0.77	0.330

[z] Means are followed by standard errors of the mean in parentheses.

FIG.	CAPTION
1.	Effect of B application rates on extractable soil B; linear regression equation: $y = 2.18 + 0.35 * x$, where y = extractable soil B (mg kg^{-1} soil fines) and x = B application rate (mg kg^{-1} soil fines).
2.	Effect of B application rates on leachate B concentrations averaged over 13 weeks; linear regression equation: $y = 0.15 + 0.10 * x$, where y = average leachate B concentration (mg L^{-1}) and x = B application rate (mg kg^{-1} soil fines).
3.	Effect of increasing average leachate B concentrations on dry weight (A) and area (B) of new leaves of 'Sharwil' avocado trees grown for 13 weeks after initiation of B treatments. Nonlinear regression equations: (A) $y = x/(0.014 + 0.011 * x + 0.013 * x^2)$, where y = dry weight of new leaves per plant (g) and x = average leachate B concentration (mg L^{-1}); and (B) $y = x/(0.88 + 0.86 * x + 0.52 * x^2)$, where y = area of new leaves per plant (m^2) and x = average leachate B concentration (mg L^{-1}).
4.	Effect of increasing B application rates on B concentrations in new leaves of 'Sharwil' avocados sampled nine weeks after initiation of B treatments. Quadratic regression equation: $y = 22.2 + 5.65*x - 0.0267*x2$, where y = foliar B concentrations (mg kg^{-1}) and x = applied B, mg kg^{-1} soil fines.

5. Effect of increasing B concentrations in the youngest, fully expanded leaves on dry weight (A) and area (B) of new leaves of 'Sharwil' avocado trees grown for 13 weeks after establishment of B treatments. Nonlinear regression equations: (A) $y = x/(2.23 - 0.058 * x + 0.000907 * x^2)$, where y = dry weight of new leaves (g) and x = foliar B concentration (mg kg^{-1}); and (B) $y = x/(55 - 0.024 * x + 0.023 * x^2)$, where y = area of new leaves (m^2) and x = foliar B concentration (mg kg^{-1}).

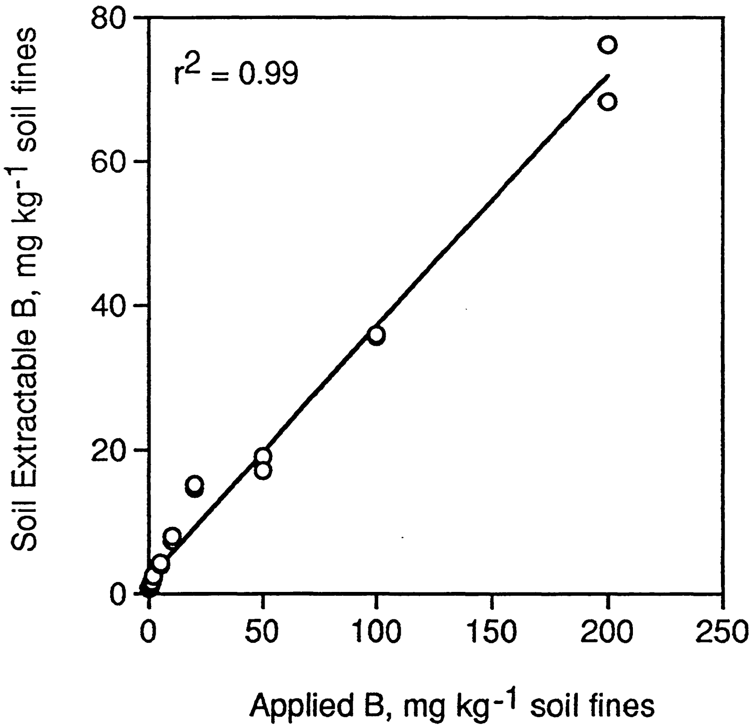


Fig 1, Miyamoto

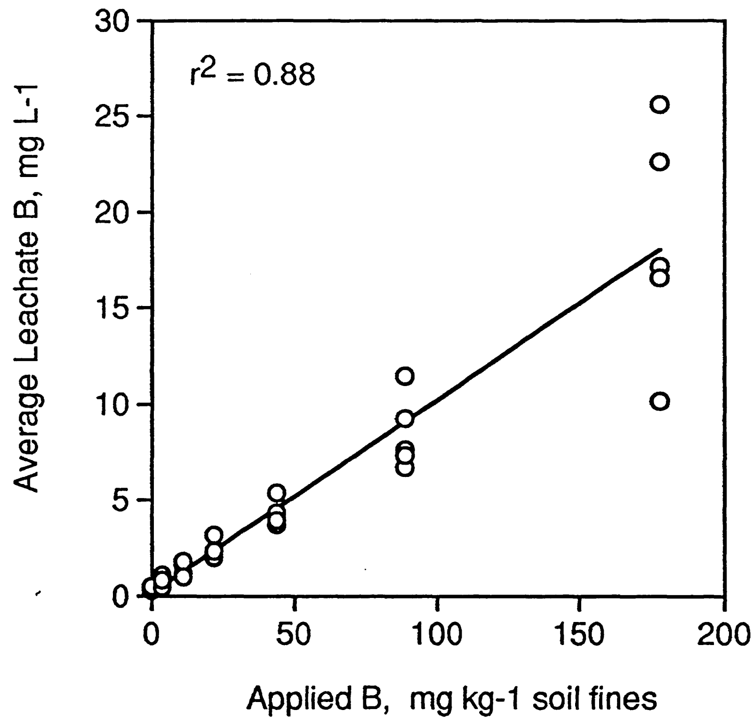
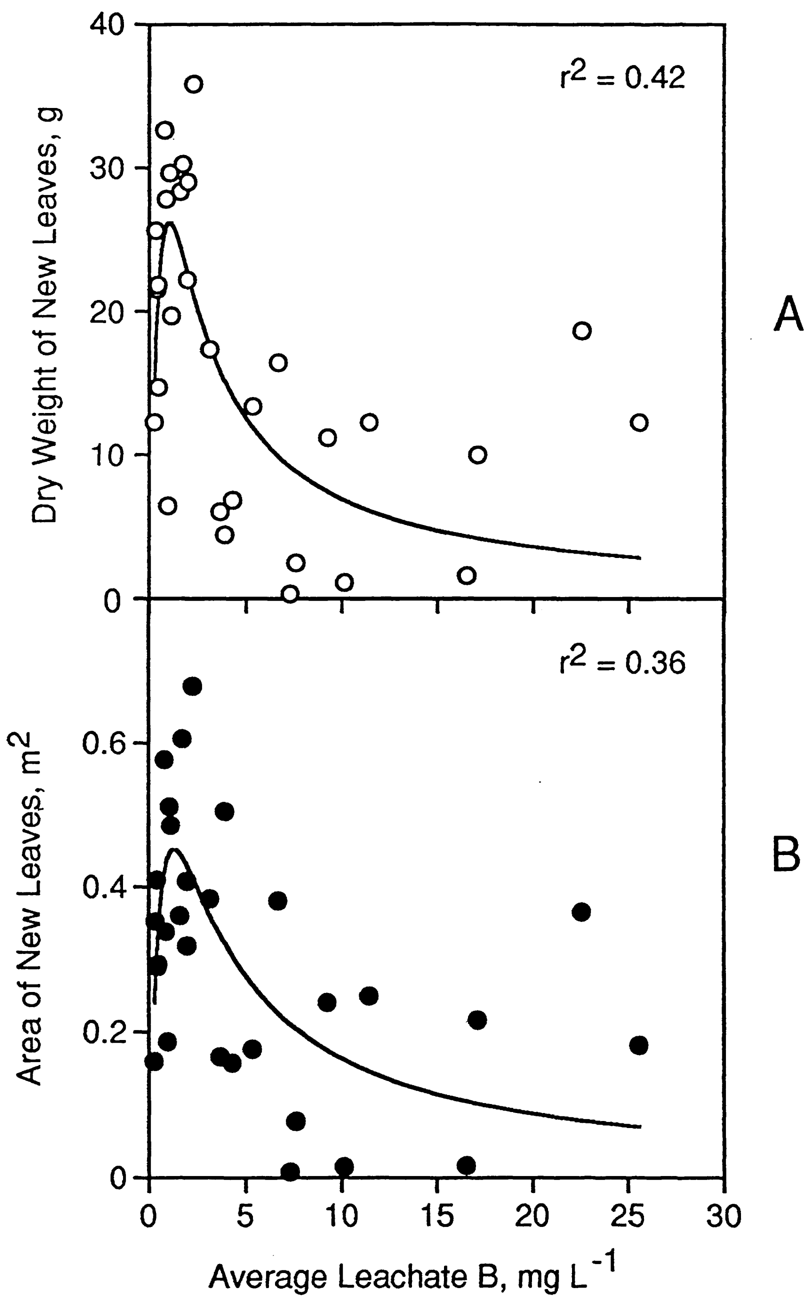
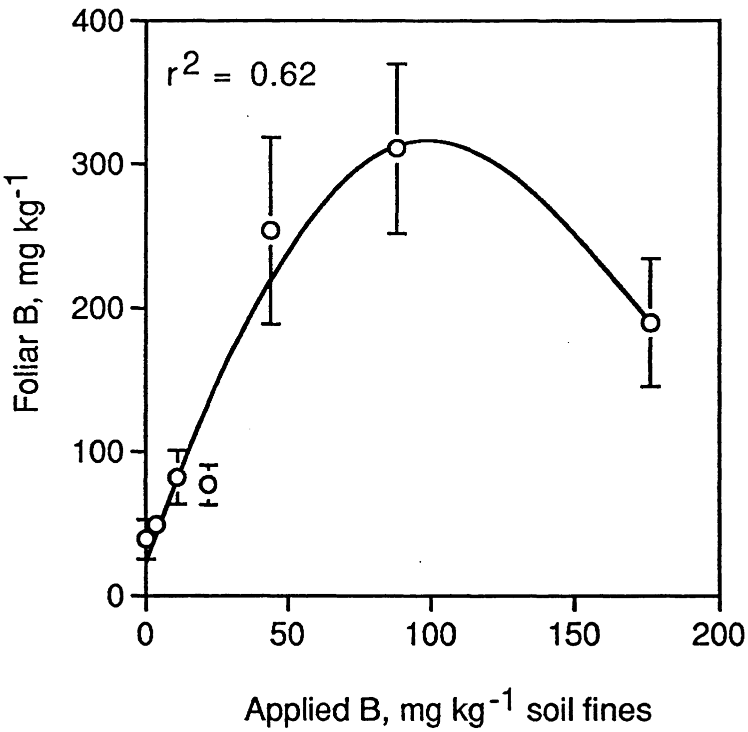


Fig. 2, Miyasaka

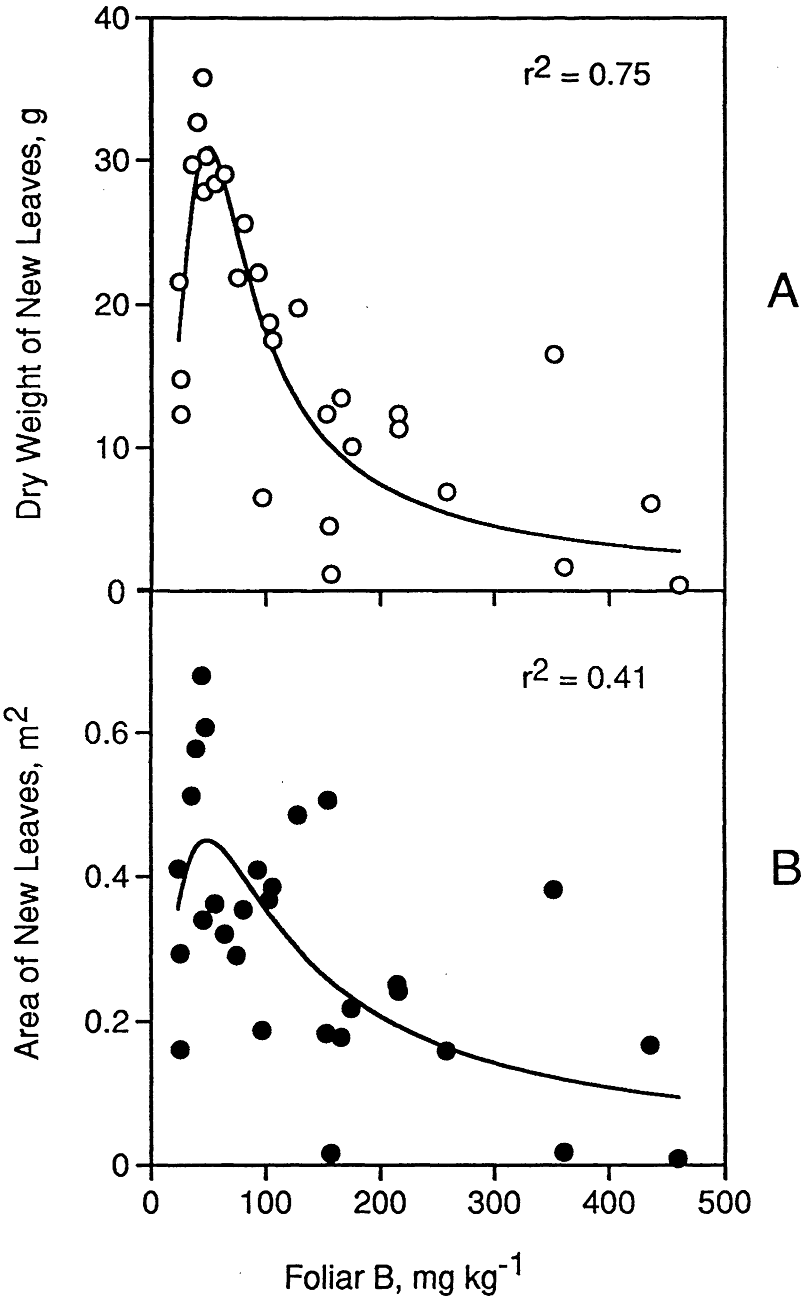


40
30
20
10
0
Dry Weight of New Leaves, g
r2 = 0.42
A
r2 = 0.36
0.6
0.4
0.2
0
Area of New Leaves, m2
B
0
5
10
15
20
25
30
Average Leachate B, mg L -1



r2 = 0.62
Foliar B, mg kg-1
400
300
200
100
0
0
50
100
150
200
Applied B, mg kg-1 soil fines

Fig. 4,



40
30
20
10
0
Dry Weight of New Leaves, g
r2 = 0.75
A
0.6
0.4
0.2
0
Area of New Leaves, m2
r2 = 0.41
B
0
100
200
300
400
500
Foliar B, mg kg-1

Fig. 5, 18 y...